

Effects of Selected Inorganic
Leachates on Clay Permeability

Duke Univ., Durham, NC

Prepared for

Environmental Protection Agency, Cincinnati, OH

1987



U.S. Department of Commerce
National Technical Information Service

NTIS

TECHNICAL REPORT DATA (Please read instructions on the reverse before completing)		
1. REPORT NO. EPA/600/J-87/338	2.	3. PB88-202494
4. TITLE AND SUBTITLE Effects of Selected Inorganic Leachates on Clay Permeability (Journal Version)	5. REPORT DATE 1987	
	6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) J. Jeffrey Peirce, Goran Sallfors, Thomas A. Peel, Kelley A. Witter	8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Dept. of Civil & Environmental Engineering Duke University Durham, NC 27706	10. PROGRAM ELEMENT NO.	
	11. CONTRACT/GRANT NO. Contract # 68-03-3149	
12. SPONSORING AGENCY NAME AND ADDRESS Hazardous Waste Engineering Research Laboratory Office of Research and Development U. S. Environmental Protection Agency Cincinnati, OH 45268	13. TYPE OF REPORT AND PERIOD COVERED	
	14. SPONSORING AGENCY CODE EPA/600/12	
15. SUPPLEMENTARY NOTES REF: Journal of Geotechnical Engineering, 113(8):915-919, August 1987		
16. ABSTRACT Abstract: Hydraulic conductivity test results for three field clays exposed to two inorganic chemicals are documented. The hydraulic conductivities of clays exposed to waste chemicals is an important consideration in the selection of a liner material for a hazardous waste containment facility. In the past, a great deal of testing has been conducted to determine the effects various organic liquids have on the hydraulic conductivity of compacted clays; however, few test results have documented the effects inorganic liquids have on clays. In this research project, the hydraulic conductivities of three field clays; White Store, Hoytville, and Faceville permeated with ferric chloride (500 mg/l) and nickel nitrate (50 mg/l & 300,000 mg/l) were determined using both fixed and flexible-wall permeameters. The effectiveness of five laboratory tests for predicting the effect inorganic chemicals may have on clay particles were also evaluated. Results indicate that at the concentrations tested, neither ferric chloride nor nickel nitrate significantly altered the hydraulic conductivities of the three clay soils. The results from the predictive tests are seen to be inconclusive.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
REPRODUCED BY U.S. DEPARTMENT OF COMMERCE National Technical Information Service SPRINGFIELD, VA. 22161		<i>see back of page</i>
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 8
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EFFECTS OF SELECTED INORGANIC LEACHATES ON CLAY PERMEABILITY

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EPJ/600/J-87/338
JOURNAL ARTICLE

INTRODUCTION

Compacted clays are widely used as liner materials for the containment of hazardous wastes. Therefore, selected research and commercial laboratories across the nation have conducted tests to determine the effect various chemicals have on clay hydraulic conductivities. Most tests have been conducted using organic chemicals (Brown and Anderson 1983; Foreman and Daniels 1984; Green, et al. 1983), and several have shown large increases of hydraulic conductivity. The increases in hydraulic conductivity have been attributed to a reduction in the thickness of the double-layer surrounding the clay particles, and also to increasing sidewall leakage due to shrinkage. The purpose of this research is to investigate the effect of selected inorganic chemicals and type of permeameter (fixed- or flexible-wall cell) on the hydraulic conductivity of three, natural, compacted clays.

PROPERTIES OF SOILS AND PERMEANTS

Three natural clays were selected for testing in this study: White Store clay from Durham County, North Carolina; Hoytville clay from Woods County, Ohio; and Faceville clay from an actual landfill site in Clarendon County, South Carolina. These soils are primarily composed of montmorillonite, illite, and kaolinite, respectively, which provide a wide range of clay minerals to be studied. A summary of the various soil properties is shown in Table 1.

The selection of the inorganic chemicals used for laboratory testing were based on the following criteria:

1. The selection should represent constituents of inorganic fluids found under field conditions.
2. The selection should represent concentrations of inorganic fluids found under field conditions.

Based on these criteria, ferric chloride (500 mg/L) and nickel nitrate (50 mg/L) were selected as representative leachates. The selection of these

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Note.—Discussion open until January 1, 1988. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on May 10, 1985. This paper is part of the *Journal of Geotechnical Engineering*, Vol. 113, No. 8, August, 1987. ©ASCE, ISSN 0733-9410/87/0008-0915, Paper No. 21729.

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TABLE 1.—Summary of Natural Clay Characterization

Characterization (1)	Natural Clay		
	White Store (2)	Hoytville (3)	Faceville (4)
Grain size distribution:			
Percent sand	45%	19%	20%
Percent silt	37%	38%	43%
Percent clay	18%	43%	37%
Specific gravity	2.57	2.77	2.59
Organic content	4%	3%	6%
Shrink-swell potential ^a	High	Medium/High	Medium
Liquid limit percent	74–79	46–48	50–52
Plastic limit percent	24–28	15–19	17
Optimum water content percent	22	18	23
Maximum dry density (kN/m ³) ^b	15.3	16.4	15.1
Cation exchange capacity (meq/100 g)	6.825	9.667	7.541

^aShrink-swell potential estimated per method cited by Mitchell (1976).

^b1 kN/m³ = 6.36 lbs/cu ft.

permeants provides a divalent and trivalent metal salt for study. A nickel nitrate solution of approximately 300 g/L (1 M) was also used to ensure that the cation exchange capacities of the clays were exceeded. Distilled water, mixed with calcium sulfate, to a 0.01 N solution widely used by other researchers, was used as the standard water for all the laboratory tests conducted.

SAMPLE PREPARATION, EQUIPMENT, AND PROCEDURES

All the clay samples were compacted at a moisture content slightly above optimum and using a modified version of ASTM-D-698 Method A(2) [1]. For the fixed-wall permeameter, a 5.5-lb (2.5-kg) hammer with a diameter of 2 in. (5 cm) was used. The clay was compacted to a depth of 2 in. (5 cm) in a 4-in. (10-cm) diameter mold. Clay samples were compacted in two even layers, with the first layer receiving 16 hammer blows and the second receiving 17. The 33 blows corresponds to a compactive energy of 12,432 ft-lb/cu ft (60.62 m-t/m³). The compaction procedure is the same for the flexible-wall permeameter, except that the hammer weights only 2.67 lbs (1.21 kg) and has a diameter of 1.4 in. (3.56 cm) while the compaction mold is 2.8 in. (7.11 cm) in diameter. The compactive energy applied to the flexible wall sample was 12,364 ft-lb/cu ft (60.29 m-t/m³). The compactive energies applied to both types of samples correspond well with the ASTM standard of 12,375 ft-lb/cu ft (60.34 m-t/m³). The equipment used consists of modifications to standard fixed-

wall permeameters and triaxial cells. These units have been designed and constructed to resist inorganic chemical attack, and have held up well during testing.

All fixed-wall permeameter tests were conducted using hydraulic gradients ranging from 65 to 190, while all flexible-wall tests were performed at a hydraulic gradient of 200. No differences were observed between the fixed-wall and flexible-wall hydraulic conductivity results.

All clay samples were initially permeated with at least one pore volume of water before they were permeated with the chemical solutions. The pH of all the leachates was monitored throughout this project. Atomic absorption analysis was also conducted on selected clay/chemical combinations.

RESULTS AND ANALYSIS

Hydraulic conductivity results obtained in this research are listed in Table 2. Sample graphs which illustrate the different clay/chemical combinations and the resultant hydraulic conductivity values as measured in the fixed-wall permeameters are given in Figs. 1 and 2.

No significant changes in the hydraulic conductivities of any of the clays occurred upon permeation with any of the test chemicals previously described, even with the passage of as many as 50 pore volumes of chemical into the samples. Hydraulic conductivity is a parameter which normally exhibits a large amount of variation. Thus, for the purpose of this project, a significant change was considered to be an order of magnitude or more. From the figures containing the hydraulic conductivity plots, it is seen that the data gathered in this research exhibited little variation.

TABLE 2.—Hydraulic Conductivity Test Results ($\text{cm/s} \times 10^{-9}$)

Clay (1)	Fixed-Wall Test		Flexible-Wall Test	
	Short-term (2)	Long-term (3)	Short-term (4)	Long-term (5)
White Store clay:				
Water	2.3 ± 0.3	1.6 ± 0.1	2.8 ± 1.6	1.7
500 mg/L FeCl_3	3.7 ± 1.0	6.2 ± 2.0	2.1	ND
50 mg/L $\text{Ni}(\text{NO}_3)_2$	2.8 ± 0.6	3.0 ± 0.5	2.0	ND
300 g/L $\text{Ni}(\text{NO}_3)_2$	2.2 ± 0.5	ND	ND	ND
Hoytville clay:				
Water	1.0 ± 0.3	1.6 ± 2.8	0.8 ± 0.3	ND
500 mg/L FeCl_3	1.0 ± 0.1	ND	1.3	ND
50 mg/L $\text{Ni}(\text{NO}_3)_2$	0.8 ± 0.1	ND	0.9	ND
300 g/L $\text{Ni}(\text{NO}_3)_2$	0.8 ± 1.4	ND	ND	ND
Faceville clay:				
Water	3.8 ± 0.8	5.2 ± 1.3	6.3 ± 1.4	ND
500 mg/L FeCl_3	6.4 ± 0.5	8.0 ± 6.9	6.2	ND
50 mg/L $\text{Ni}(\text{NO}_3)_2$	4.3 ± 2.6	11.0 ± 6.0	5.6	ND
300 g/L $\text{Ni}(\text{NO}_3)_2$	5.1 ± 1.9	ND	ND	ND

Note: ND indicates no data available. Ranges indicate 90% confidence intervals if replicate data was available.

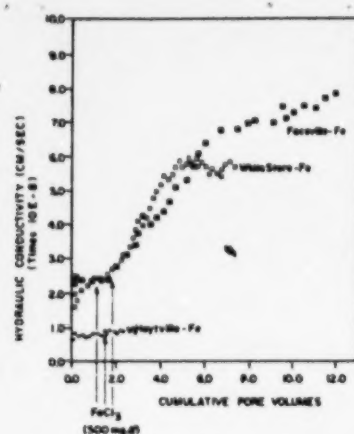


FIG. 1.—Fixed-Wall Hydraulic Conductivity Graph (Ferric Chloride)

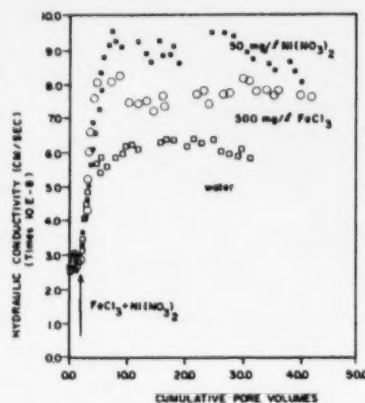


FIG. 2.—Long-Term Fixed-Wall Hydraulic Conductivity Graph (Faceville Clay)

Fig. 1 shows that, in the fixed-wall permeameters, there is a slight increase in the hydraulic conductivity of White Store and Faceville clay upon permeation with the ferric chloride solutions (500 mg/L). However, Fig. 2 shows how the hydraulic conductivities of these clays stabilized after the passage of a large number of pore volumes of the chemical permeants. This slight increase may be due to a small amount of flocculation occurring within the clay samples. Faceville clay also exhibited a slight increase in hydraulic conductivity over time with permeation of water. Hoytville clay was fairly resistant to changes in hydraulic conductivity with exposure to all the test solutions.

Larger increases in the hydraulic conductivities of the clays was expected to occur upon permeation with the concentrated 300 g/L nickel nitrate solution since a large amount of flocculation was expected. However smaller increases in hydraulic conductivity were observed for all three clays upon permeation with the 300 g/L nickel nitrate solution than were obtained for the dilute solutions. The precipitation of insoluble salts within the pore spaces of the clay samples probably counteracted the effects of flocculation and caused the lower-than-expected increases in hydraulic conductivity.

Atomic adsorption studies conducted on the Faceville clay leachate showed that all the low concentrations of ferric chloride and nickel nitrate the concentration of the metals in the leachate never approached the initial concentration of the permeating solution. That indicates that at these low concentrations the cation exchange capacities of the clays were never met. However, with the concentrated nickel nitrate solution, the concentration of nickel in the leachate did approach the initial concentration of the permeating solution, indicating that the cation exchange capacities of the clay had been exceeded.

CONCLUSIONS

Compared with water, ferric chloride and nickel nitrate at the concentrations tested do not affect the hydraulic conductivity of White Store clay, even after the passage of as many as 10 pore volumes of permeant into the clay.

Compared with water, ferric chloride and nickel nitrate do not affect the hydraulic conductivity of Hoytville clay at the concentrations tested, even with the passage of as many as 17 pore volumes of permeant into the clay. Of the three clays tested, Hoytville appeared to be the least responsive to these test permeants. This could be explained by the fact that Hoytville has the highest clay fraction of the three clays under consideration.

Compared with water, ferric chloride and nickel nitrate do not affect the hydraulic conductivity of Faceville clay at the concentrations tested, even with the passage of as many as 50 pore volumes of permeant into the clay.

The selection of a "standard water" is a critical consideration in hydraulic conductivity testing. As expected, results from subsequent settling tests indicate, for example, that 0.01 N calcium sulfate flocculates all three clays. Therefore, at the concentration of calcium sulfate used in this study, the flocculation process could mask any effect on hydraulic conductivity that the nickel nitrate and ferric chloride solutions may have. Thus, all clay/chemical compatibility tests must be conducted using local water to document site-specific conditions; high concentrations of calcium sulfate are not recommended as a "standard water."

The clay fraction of materials suggested for use as barriers to prevent hazardous waste migration must be closely monitored. Materials having high clay fractions could be the least responsive to test permeants, and thus could be most suitable as liner materials.

ACKNOWLEDGMENTS

This research was funded by the United States Environmental Protection Agency and the Natural Science Foundation. The writers wish to express thanks to Walter Grube of the U.S. EPA, Garrie Kingsbury of the Research Triangle Institute, and Edward Bryan of the NSF.

APPENDIX.—REFERENCES

- Brown, K. W., and Anderson, D. C. (1983). "Effects of organic solvents on the permeability of clay soils." EPA-600/2-83-016, U.S. Envir. Protection Agency, Washington, D.C.
- Foreman, D. E., and Daniels, D. E. (1984). "Effects of hydraulic gradient and method of testing on the hydraulic conductivity of compacted clay to water, methanol, and heptane." Paper presented at the U.S. Envir. Protection Agency Conf., held at Atlanta, Ga.
- Green, W. J., Lee, G. F., Jones, R. A., and Palit, T. (1983). "Interaction of clay soils with water and organic solvents: Implications for disposal of hazardous wastes." *Envir. Sci. & Tech.*, 17, 278-282.
- Mitchell, J. K. (1976). *Fundamentals of soil behavior*. Wiley, New York, N.Y.

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